dena
German Energy Agency

Component of an Integrated Energy Transition

Roadmap Power to Gas

Strategieplattform
Power to Gas

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Summary

With this roadmap, the Power to Gas strategy platform provides an **overview of the contribution Power to Gas can make to achieving climate policy goals**. The Power to Gas roadmap comes to the following conclusions:

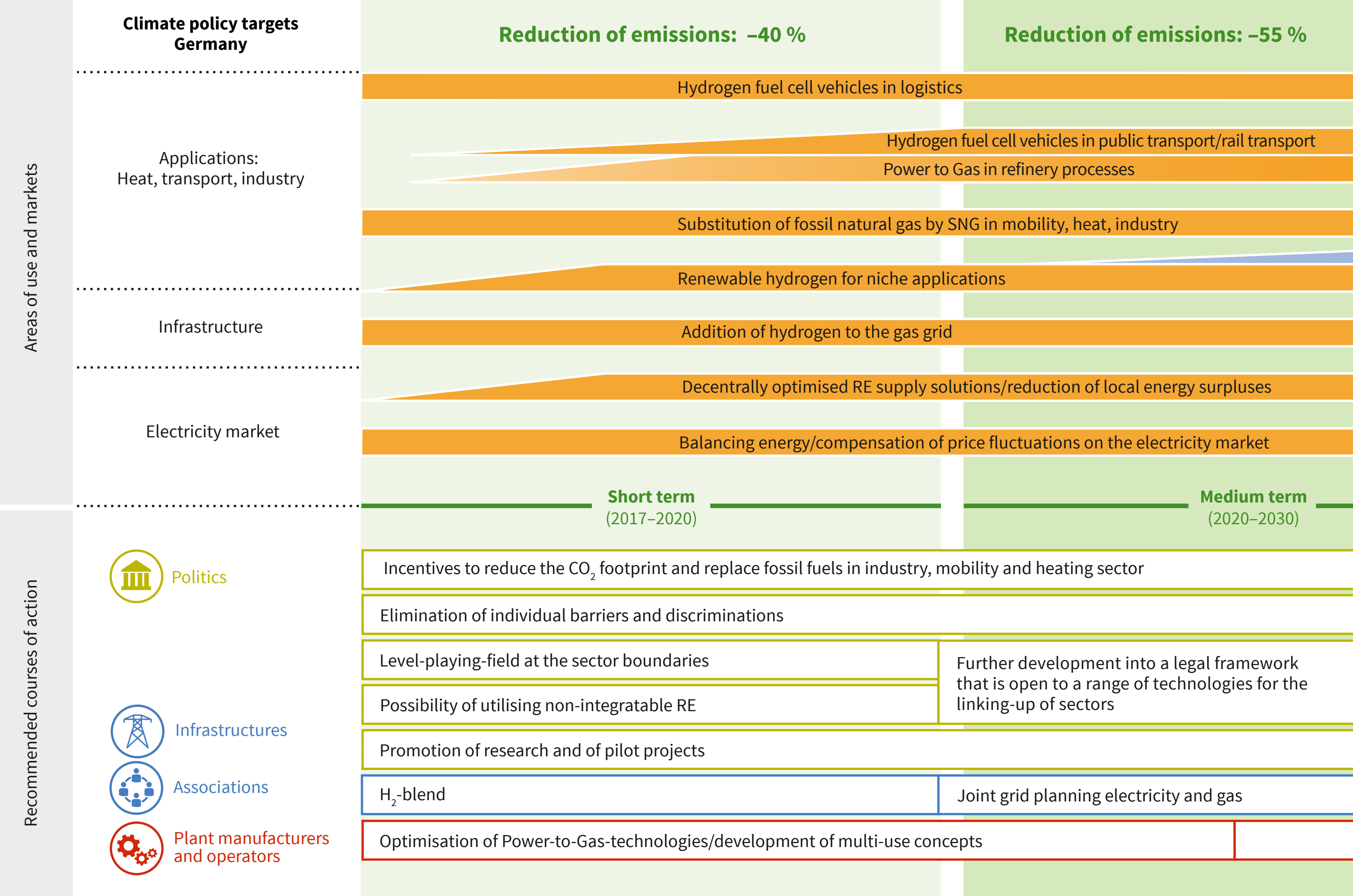
- Power to Gas is, as an **essential pillar of an Integrated Energy Transition, necessary to meet the climate protection targets of Germany**. Power to Gas will make an important contribution towards covering the energy requirement of the sectors heat, transport and industry while having a small CO_2 footprint.

- In **some areas, Power to Gas is the only technically viable way to reduce the CO_2 footprint**, because from today's perspective the direct use of electricity does not seem to be possible nationwide. Furthermore, the technology fulfils tasks that are beneficial to the electricity system and cushions the challenges within an increasingly electrified energy system containing a large proportion of renewable energies.

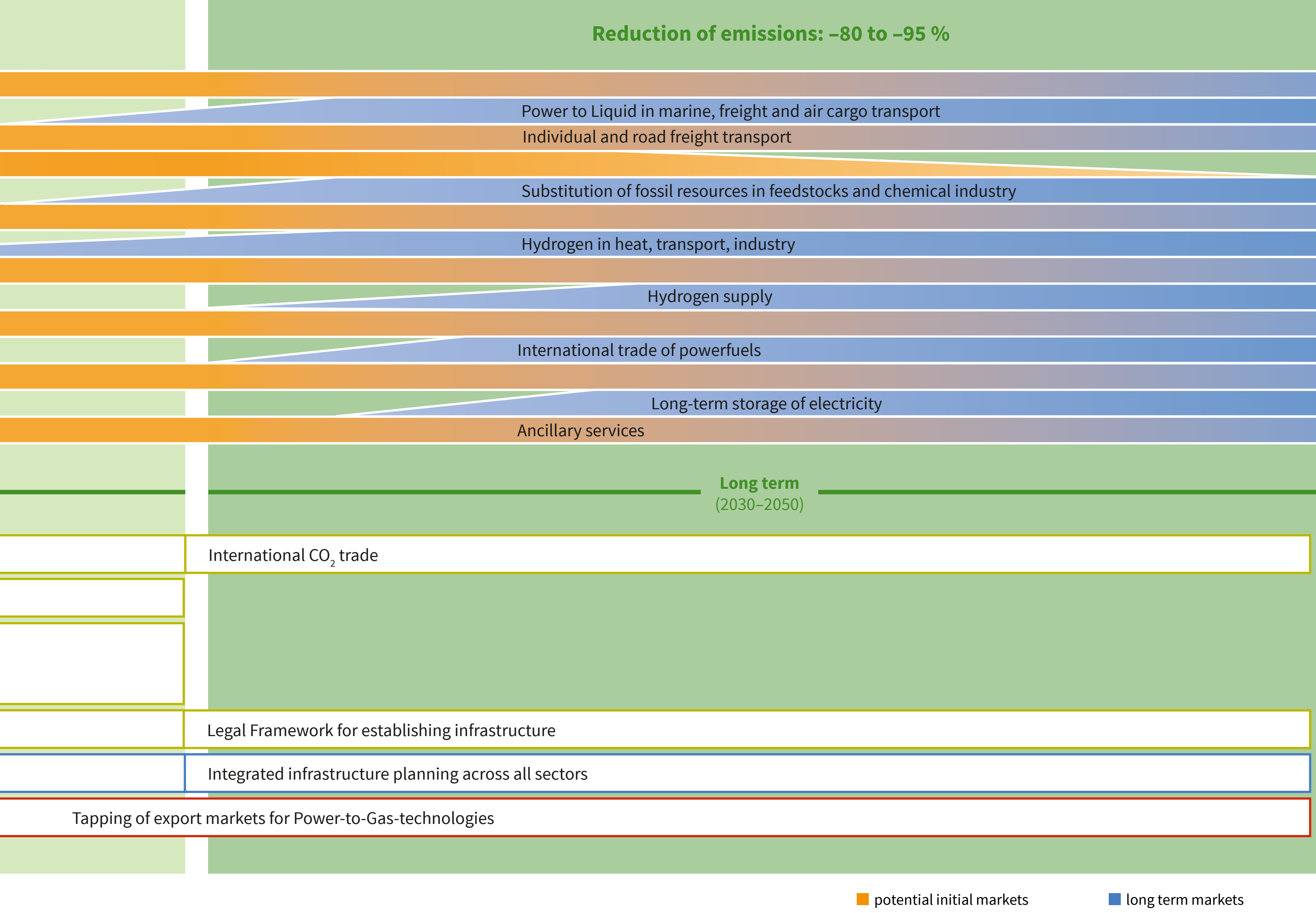
- **At present, the technology is economically viable only in exceptional cases**, thus hampering the momentum of expansion. For Power to Gas to be ready for use at an acceptable cost, the industrialisation and market development of Power to Gas should begin now. To this end, a **legal framework which is open to a range of technologies** must be created as a prerequisite for the economical operation of Power to Gas plants.

- **Power-to-Gas- or Power-to-Liquid-products provide the perspective of being traded on the global market** and thus of substituting fossil fuels. Countries with good locations for renewable energies have a particular advantage in terms of production powerfuels. **Germany should help to promote the development of global markets and strive for technological leadership.**

- An important basis for the future energy system are, besides the supply of electricity, the gas grid as well as the infrastrucutral facilities providing liquid energy carriers.



Areas of use for Power to Gas and recommended courses of action:
The chart shows central areas of application and initial markets for Power to Gas and the recommended course of action which are necessary for a market launch.


Reduction of emissions: –80 to –95 %
Power to Liquid in marine, freight and air cargo transport
Individual and road freight transport
Substitution of fossil resources in feedstocks and chemical industry
Hydrogen in heat, transport, industry
Hydrogen supply
International trade of powerfuels
Long-term storage of electricity
Ancillary services
Long term
(2030–2050)
International CO_2 trade
Legal Framework for establishing infrastructure
Integrated infrastructure planning across all sectors
Tapping of export markets for Power-to-Gas-technologies
potential initial markets
long term markets

Introduction

The energy and climate policy targets in Germany require a reduction in greenhouse gases by 80 to 95 per cent by 2050. To this end, it is important not only to significantly increase energy efficiency but also to use renewable energies in all sectors. Here, Power to Gas is a key technology.

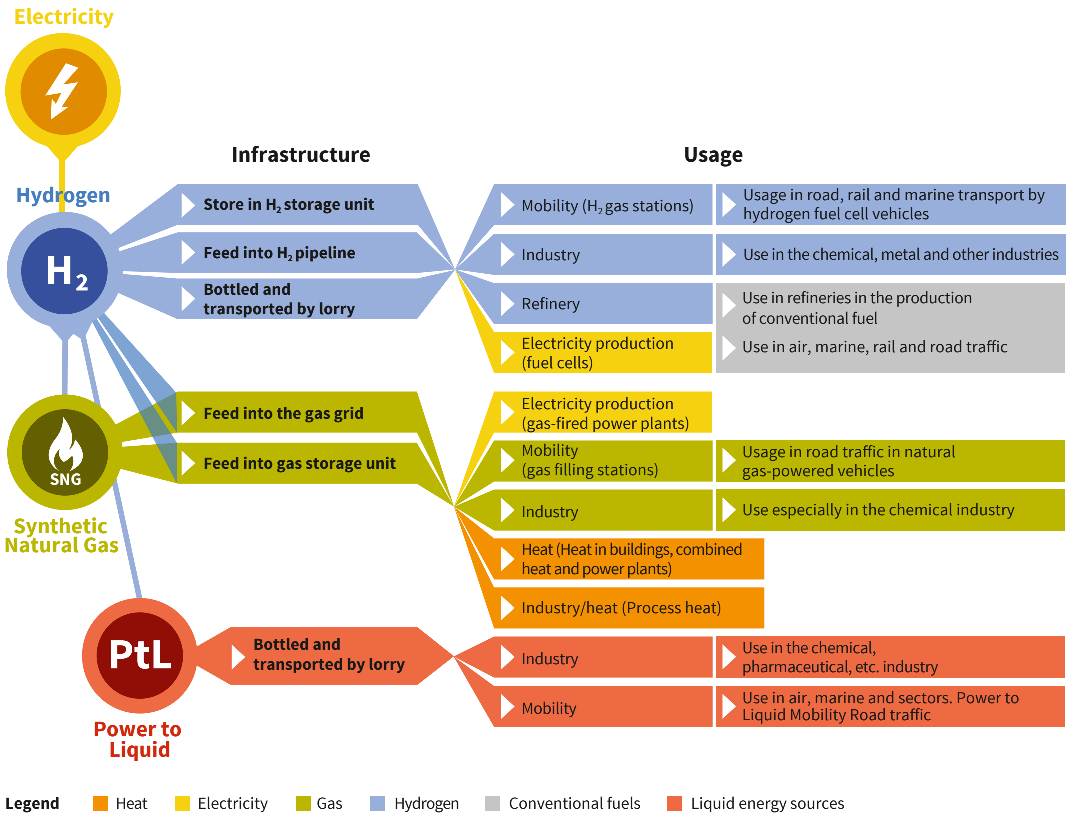
The roadmap
With this roadmap, the Strategy Platform Power to Gas provides an overview of the contribution Power to Gas can make to achieving climate policy goals. The Power to Gas roadmap shows the current and future role of the technology in the energy system, initial entry markets and existing regulatory, infrastructural and technical barriers. It gives recommendations for action in order to help all stakeholders to develop suitable framework conditions and functioning business models for Power to gas.

The Strategy Platform Power to Gas
Specialist stakeholders from industry, associations and science have joined forces on the Strategy Platform Power to Gas to further develop the system solution Power to Gas, present it to a wider public and consult on its future use with decision-makers. The Strategy Platform underlines the necessity of storage for a future energy system involving a high proportion of renewable energies and supports the use of Power to Gas in order to integrate power from renewable sources into the overall energy system. All Power to Gas generation and usage options are treated equally, and hence the development of different business models is considered.

Further information on Power to Gas and publications of the Strategy Platform can be found at:
www.powertogas.info

What is Power to Gas?

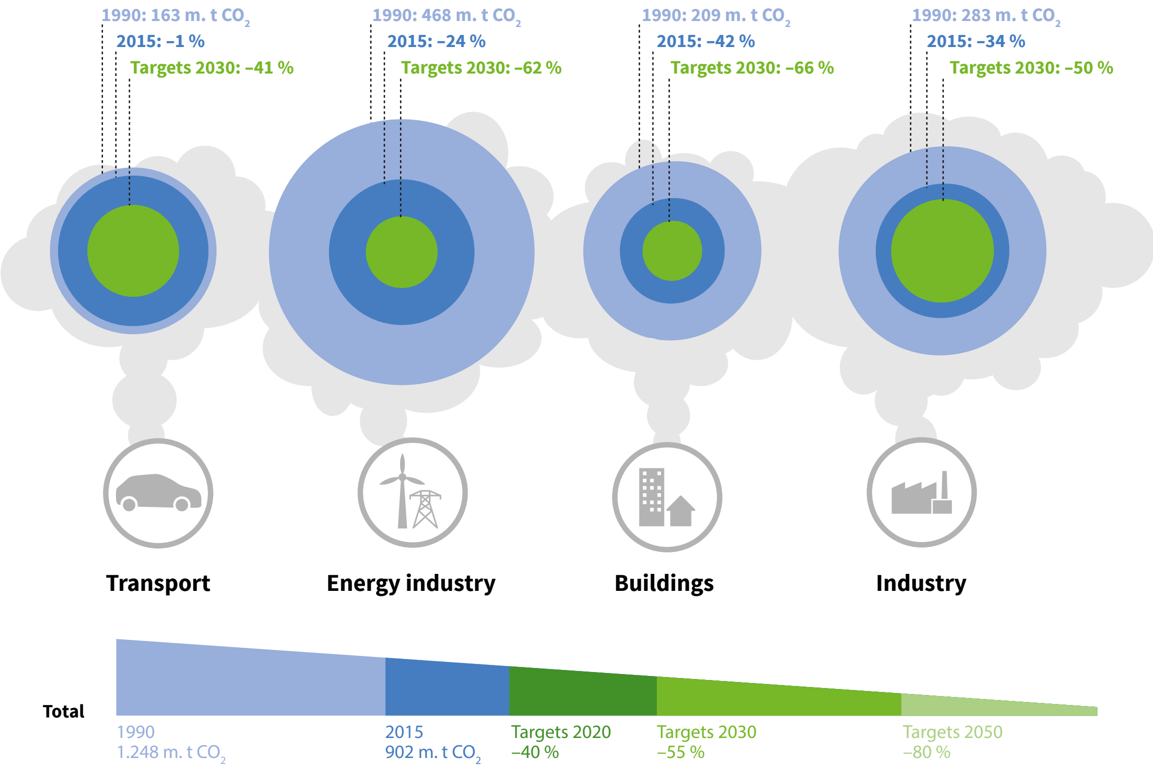
The idea behind Power to Gas is to break down water by electrolysis using electricity from renewable energy sources and use the **hydrogen** produced either directly or process it into **methane** or **liquid energy carriers**. These renewable energy sources can be integrated into **existing infrastructures** respectively be stored there and then **be used in various applications**. With this technology renewable electricity can be converted into gaseous (Power to Gas, PtG) or liquid (Power to Liquid, PtL) energy carriers, which can help **reduce greenhouse gases in all sectors**.



Usage options Power to Gas

The challenge posed by climate protection targets

Germany has set itself ambitious targets in order to reduce greenhouse gases. Greenhouse gas emissions are to be brought down 55 percent by 2030 and 80 to 95 percent by 2050 compared to 1990 levels. Power-to-Gas-products can help to achieve these goals by replacing fossil fuels in all sectors, e.g. crude oil, natural gas, coal, gasoline, diesel or heating oil. This requires a further roll-out of renewable energies that goes far beyond the current scope.



CO_2 emissions and climate protection targets in Germany by sector (sources: Federal Government (2016): Climate Protection Report 2016, Federal Government (2016): Climate Action Plan 2050, Federal Environment Agency (UBA) 2017: Environmental Indicators – Indicator: Greenhouse Gas)

The Integrated Energy Transition with Power to Gas

Power to Gas is a pivotal technology to achieve the energy and climate policy goals.

The challenge posed by an Integrated Energy Transition is to harmonise an increasing number of components from all sectors with each other and combine them into an intelligent and sustainable energy system. Power to Gas will play an important systemic role by stabilising the supply of energy and offsetting seasonal and spatial fluctuations in the production of electricity from renewable sources.

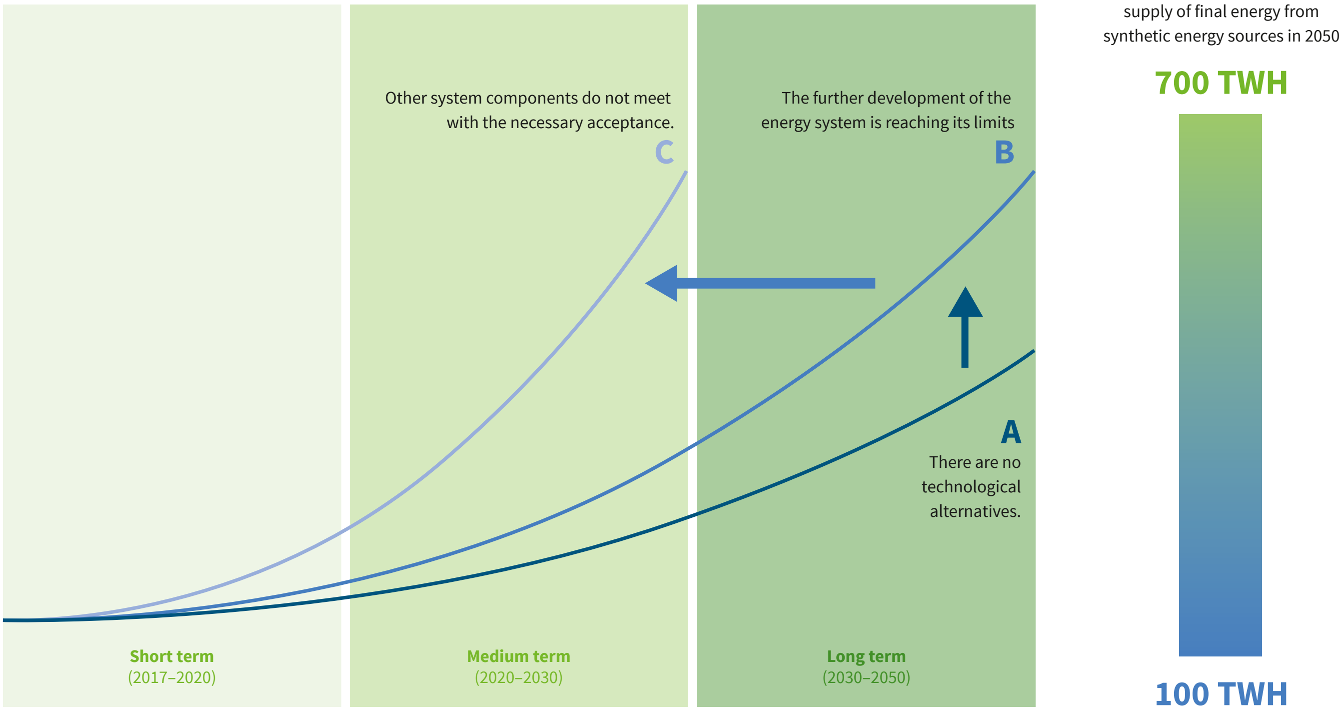
- Power to Gas is needed in particular where there are **no technological alternatives and the direct use of renewable electricity is not possible**.
- Power to Gas is needed where the **further development of the energy system based on extensive electrification together with the use of renewable energies reaches its limits**.
- Power to Gas could be implemented where **other system or application components do not meet with the necessary** acceptance or do not satisfy the requirements or needs of users.
- Power to Gas makes sense where the **existing infrastructures can be used,** thus **cutting costs (e.g. for new infrastructures)**.

Current studies from the energy industry predict that **in 2050 synthetic energy carriers in the range of 100 up to over 700 TWh will be required for a succesful energy transition**. PtG is considered to be, in addition to surplus storage, a key way of meeting the energy needs of other sectors in a low-carbon manner. **Several studies show that scenarios which are based on the assumption of a wide mix of technologies could entail considerably lower costs up to 2050 than scenarios which are based solely on a higher level of electrification.**

Not the entire quantity of PtG/PtL products required for the German market needs to be produced in Germany. It could be economically reasonable to produce parts of the required PtG/PtL in countries with more favourable renewable energy locations, and then import it.

Power to Gas within the energy system

What role can Power to Gas play within the energy system?



Power to Gas: Areas of use in detail (1)

Below **the areas of use where PtG is appropriate** are described. It becomes clear that an increased use of Power to Gas becomes more urgent the sooner that energy system reaches its limits and other system components do not meet the requisite **acceptance**.

Area of use A:
There are no technological alternatives because the direct use of electricity from renewable energy sources is not possible or difficult.

Marine, air and long-distance transport: Power to Gas can provide fuels with low carbon footprint, that can substitute fossil fuels. Due to the required distances and the high energy demand of these application fields battery electric propulsion is not or just to a limited extent suitable.

Seasonal storage of energy: Power to Gas can function as a seasonal energy storage system. This is particularly relevant for the demand peaks which occur in the winter months in the heating sector. Converted into hydrogen or methane, the energy can be stored in the existing natural gas infrastructure or a further developed hydrogen infrastructure.

Raw materials industry and chemical industry: Hydrogen and synthetic gas are important feedstocks in the chemical industry and in refineries. With the help of Power to Gas plants, these raw materials can be produced from water, renewable electricity and CO_2 and thus replace fossil raw materials. The chemical use of hydrogen as an alternative, regenerative reducing agent is a promising option in the steel industry as a way to avoid greenhouse gases.

Power to Gas: Areas of use in detail (2)

Area of use B:
Power to Gas is needed where the further development of the energy system, which is based on an extensive electrification together with the use of renewable energies, reaches its limits.

Relief of grid bottlenecks: Power to Gas plants can, by being run in a way which is beneficial to the system, relieve the transmission and distribution grids and thus reduce costs. In 2016, grid operators cut off more than 3.7 TWh of electricity from subsidised EEG plants because it was impossible to integrate the electricity into the grid. With increasing electrification of the sectors heat, industry and transport, the load flows in the grids are likely continue to increase.

Increasing flexibility: Power to Gas can help make the electricity system more flexible by having balancing energy at the disposal of the plants or by offsetting fluctuations on the electricity market.

Backing up guaranteed output: Synthetic methane from Power to Gas plants can be used to provide guaranteed output from gas turbines, gas engines and combined heat and power plants with low greenhouse gas emissions. This is especially important in “the cold dark slack” periods.

Power to Gas: Areas of use in detail (3)

Area of use C:
Other system or application components do not meet with the prerequisite acceptance or do not fulfil the users' requirements.

During the transformation of the energy system, the most efficient technologies not always meet the necessary acceptance, or are appropriate under given technical prerequisites. Power to Gas offers new solutions:

Heating sector: PtG can successively replace fossil natural gas in existing gas or fuel cell heating systems. Gas appliances are often a cost-efficient option for users. Many gas heaters will most likely still be in use after 2040.

Motorised individual and lorry transport: PtG can supplement battery-powered electric mobility. The latter is suitable above all for passenger cars and commercial vehicles with a low daily mileage. The advantage of fuel cell or natural gas vehicles, in contrast, lies in their greater range, especially when it comes to transporting heavy duty. Renewable gases possess a high energy density and offer the advantage of fast refuelling. They are therefore very suitable for commercial and longdistance traffic.

Delayed expansion of electricity grid: Problems with approval by the public and by authorities are delaying the expansion of the electricity grid. PtG makes it possible to integrate renewable electricity that cannot be used elsewhere into the energy system and at the same time supplement the electricity grid.

Space required for renewable energy sources: The expansion of renewable energy requires a lot of space. This can lead to problems in terms of public approval, just like the expansion of the electricity grid. In addition, part of the energy production can be relocated to countries with favourable locations for renewable energy and less densely populated areas. For the import of synthetic fuels with a high energy density, Power to Gas can thus open up an important pathway, because existing infrastructures for gas and liquid fuels can be used for the long-distance transport. This gives Germany the chance to import PtG/PtL products at comparatively low cost and at the same time create export markets for PtG technologies.

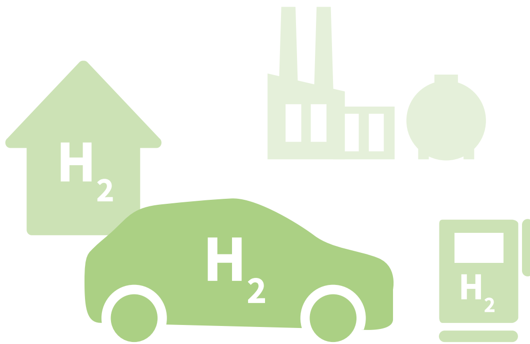
Power to Gas: Germany as a pioneer

Germany is currently playing a pioneering role in the testing and further development of Power-to-Gas-technologies. In Germany, there are more than 30 pilot projects with a combined electrolyser capacity of more than 20 MW. Other countries are also looking into individual production methods and possible applications of Power to Gas, but a large number of applications are already being tested in Germany today. Both start-ups and larger, established companies are already testing new processes, components and operational concepts and are establishing innovative springboard markets.

Other countries too, however, are increasingly turning to Power-to-Gas-technologies, including the USA, Japan, Australia, Denmark, Iceland and Switzerland.

Japan has for example decided on a wide use of hydrogen for the supply of energy during the Olympic Summer-Games in 2020. It is planned to use fuel cell systems to supply more than one million buildings (businesses and homes) and 6,000 fuel cell vehicles for city cleaning as well as more than one hundred buses for public transport.

China‘s national energy plan envisages, for example, the purchase of 300 fuel cell buses by the end of 2017 and the construction of a hybrid power plant for the production of hydrogen. Chinese companies have, among other things, shares in hydrogen technology companies or partnerships, e.g. for the conversion of buses to hydrogen.



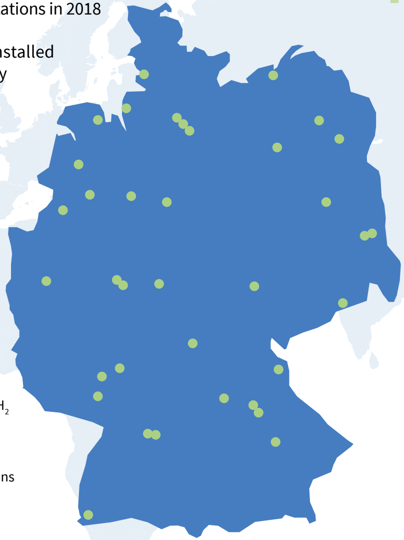
Power-to-Gas- and H_2-projects worldwide

Germany

> 30 over 30 pilot projects

32 H_2 filling stations
Goal: 100 H_2 filling stations in 2018

> 20 more than 20 MW installed electrolysis capacity



2 MW

Canada
- 2-MW PtG plant Mississauga: Feed-in of hydrogen into the natural gas grid
- 200-kW PtG plant Quebec's Raglan Arctic Wind Hydrogen Energy Storage Pilot

1.500

USA
- 1,500 fuel cell vehicles + 33 fuel cell buses
- 73 H_2 filling stations
- 225 MW fuel cells for stationary energy supply
- 2.600 km H_2 pipelines
- California: goal 100 H_2 filling stations by 2023

1,4 MW

Argentina
- 1.4-MW PtG plant from the energy provider Hychico
- Pilot project underground storage of hydrogen

17

Great Britain
- 17 H_2 filling stations
- Pilot project easyjet and Cranfield University: hybrid aeroplane with fuel cell technology

1 MW

France
- 1-MW PtG plant during research project Jupiter 1000: Feed-in of H_2 into gas grid
- 185 fuel cell vehicles and around 100 fuel cell forklifts
- Goal by 2019: 100 H_2 filling stations

Spain
Research project Sotavento: Demonstration plant 200 kW on the wind farm

Switzerland
Research project STORE&GO for integrating Power to Gas into the energy system and for testing innovative methanation techno-logies

Iceland
Hydrogen Roadmap (1998)
Goal: Develop a "hydrogen industry" by 2050

Austria
- Research project wind2hydrogen: Pilot plant for the production, storage and feeding hydrogen into the gas grid
- Research project Underground Sun Storage: for storage of hydrogen in gas storage units

20 MW

Scandinavia
- Norway: 20-MW PtL plant in the industrial park Heroya as from 2020 for the production of Blue Crude (substitute for crude oil)
- Norway: Utsira Wind Power and Hydrogen Plant (first Power to Gas pilot project 2004–2007)
- Denmark: "Hydrogen community" of Vestens-kov in Denmark:
- Project HyBalance: Megawatt demonstration plant Wind to Hydrogen
- 23 H_2 filling stations in the whole of Scandinavia

4 MW

China
- 4-MW PtG plant: Hybrid power plant to produce hydrogen from wind energy
- 5 H_2 fillings stations
- Promotion of H_2 filling stations and fuel cell vehicles in the national energy plan
- Goal: 5,000 H_2 buses by 2020

200.000

Japan
- 200,000 fuel cell systems for household energy supply
- 90 H_2 filling stations
- 2,840 fuel cell cars + 2 fuel cell buses
- Goal: use of more than 100 buses in Tokyo by 2020

10 MW

Hungary
10-MW PtG plant with methanisation belonging to the energy provider MVM

Power to Gas: Success story

In recent years, Power-to-Gas-technologies have successfully been further developed. Electrolysis technologies are already on the verge of growth.

A further reduction in investment and operating costs can be achieved scaling up quantities and sizes, standardising plant components and optimising the plant concept.

Assuming a technological learning rate comparable to that of wind energy, the specific investment costs could be reduced by 13 percent with each doubling of the plant capacity installed worldwide. Thus, **by 2050 the cost of Power-to-Gas-plants for the production of hydrogen could drop to 250 to 550 euros per kilowatt of electrolyser capacity**.

The decisive factor is that application technologies, the necessary transport infrastructures and corresponding market launch strategies continue to be developed to the same extent. Infrastructure issues in particular require a European, not just national, strategy, e.g. for feeding hydrogen into the natural gas transmission grid.

From the point of view of industrial policy, early market dissemination of Power-to-Gas-technologies in Germany could be beneficial. To allow innovation to flourish and markets to develop in this field, regulatory barriers must be dismantled and economically favourable frameworks have to be established.

Power to Gas: Current state of technology and perspectives

	ELECTROLYSIS			METHANISATION	
CURRENT SITUATION	Alkaline electrolysis	PEM electrolysis	High-temp. electrolysis (SOEC)	Catalytic methanisation	Biological methanisation
Technology Readiness Level	9	8	6	8	7
Advantages	cost-effective (large plants), long-term experience	compact design, better dynamics, good scalability, no corrosion	Increase of efficiency and cost effectiveness by utilising waste heat	good scalability, high-quality waste heat	robust, flexible, fast reaction time
Challenges	alkaline solutions, cold start and partial load behaviour	expensive materials, material requisitions	process conducted at high temperature	expensive materials, low flexibility, purity of input gases	biological system, no multi-MW plant realised yet
Efficiency	62 – 82 %	65 – 82 %	65 – 85 %	77 – 83 %	77 – 80 %
Investment costs	800 – 1.500 €/kW	900 – 1.850 €/kW	2.200 – 6.500 €/kW	400 – 1.230 €/kW	400 – 1.980 €/kW
PROSPECTS					
Efficiency	**78 – 84 %**	**75 – 84 %**	**87 – 95 %**	**77 – 90 %**	**79 – 90 %**
Investment costs	**250 – 400 €/kW**	**300 – 700 €/kW**	**270 – 800 €/kW**	**130 – 400 €/kW**	**200 – 400 €/kW**

Efficiency relating to lower heating value; investments in relation to rated capacity of the plant

Markets for Power to Gas (1)

Initial markets

In all sectors, there are signs of short-term **initial markets for Power to Gas** which offer application possibilities in the short and medium term and will probably be the first to be economically viable Full Stop. Some of them are already being tapped via pilot projects today. Initial or entry markets are important in order to reduce technology costs and at the same time develop system solutions and respond to infrastructural questions. The further development of technology also offers **opportunities with regard to industrial policy and the national economy**. A technological lead **produces competitive advantages and creates or secures jobs**; the creation of value takes place in Germany and Europe.

Some areas of application already exist which are almost economical and represent initial business opportunities. These include niche applications for industry and premium products for environmentally or image-conscious customers. In addition, markets that are easy to access, e.g. due to lower infrastructure requirements, can serve as multipliers for innovative technologies and thus have important learning effects (multiplier markets).

Initial markets for renewable hydrogen already exist, for example, for small consumers with high purchasing costs or for fuel cell systems used in emergency and uninterruptible power supply. In wastewater treatment facilities, Power-to-Gas-plants can bind emitted CO_2 for methanisation as well as generate oxygen to purify wastewater.

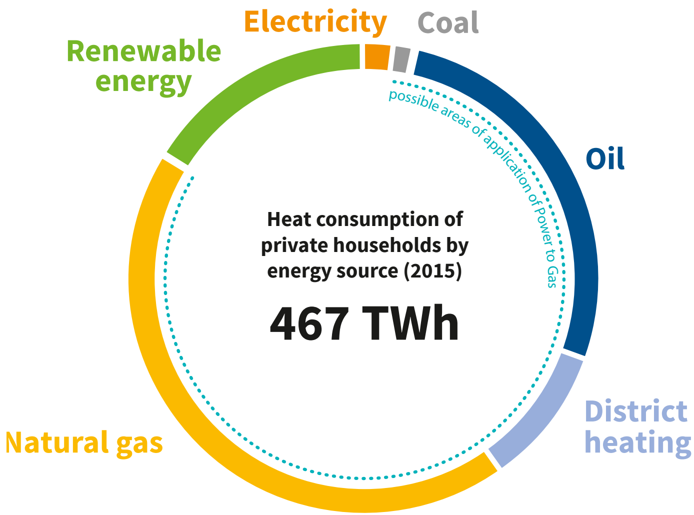
In the short and medium term, existing natural gas technologies in all sectors can pave the way for Power-to-Gas-technologies (natural gas vehicles, natural gas heating and industrial processes based on natural gas). Looking ahead, markets for fuel cell technologies may gain ground in all sectors.

Markets for Power to Gas (2)

Electricity sector and heating sector

In the electricity market Power-to-Gas-plants can provide balancing energy. Furthermore, in regions with a high installed capacity of renewable energies, they can serve as switchable loads in order to avoid grid bottlenecks. This will both reduce system costs incurred through claims for compensation due to the discontinuation of EEG plants and the cost of expanding grids. In the long term Power to Gas can, together with gas-fired power plants, function as seasonal storage in the market.

Heating sector: Synthetic methane (SNG) can partially or completely replace fossil natural gas by admixture in gas fired condensing boilers or in combination systems of gas/solar thermal energy or gas/heat pump. A great advantage is that no technical effort is required and the users can continue to use the existing heating systems.



Source: dena (2016): dena-buildings report - Statistics and analysis on energy efficiency in existing building stock

Markets for Power to Gas (3)

Transport sector

The proportion of renewable energy in the transport sector is currently only five percent, with a total final energy consumption of 726 TWh. In the transport sector, synthetic fuels from renewable electricity (hydrogen, SNG and PtL) have a high potential for reducing greenhouse gas emissions compared to fossil fuels. **PtL/PtG products** can be used in air, marine and heavy duty transport. Particularly in marine and air transport and for transporting heavy duty over long distances, there are no alternatives to liquid and gaseous fuels on the horizon, as the fuels must have a high energy density. The advantage of PtL products is that they can be used without adapting engines and infrastructures.

In passenger and local transport, there are currently various CO_2-low propulsion concepts, including battery electric, fuel cell and natural gas vehicles. The future mix of drive technologies depends not only on cost efficiency but also on customer requirements, the transport assignment and the existing infrastructure. A market launch of new drive technologies is currently severely hampered by the lack of appropriate infrastructure and vehicles. Vehicles with alternative drive technologies – hybrid, electric, natural gas, hydrogen – only accounted for 1.4 percent of new vehicle sales in 2017.

Public transport and non-electric rail transport can serve as multipliers for innovative technologies such as fuel cell technology. Because of its comparatively low demands on a nationwide infrastructure, public transport is particularly suitable for testing innovative drive technologies, alternative fuels and corresponding infrastructures. SNG and hydrogen buses offer advantages in terms of distance and refuelling time and are therefore a useful addition to battery electric buses in order to enable local emission-free mobility.

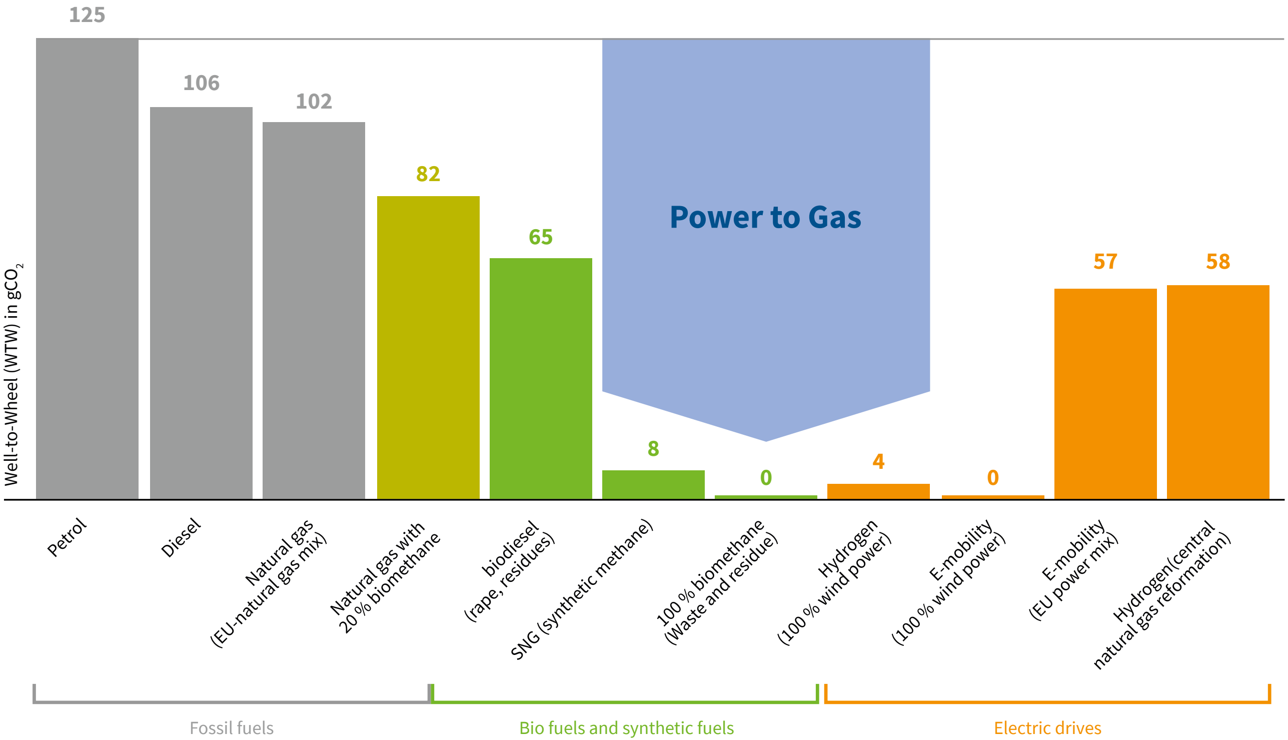
With SNG, an emission-reducing fuel already exists today which increases the use of renewable energies with natural gas vehicle technologies in private, freight and public transport, without being bound by admixture limits.

In the medium to long term, **fuel cell vehicles** could gain importance. Fuel cell industrial trucks, used primarily in logistics or at airports, represent an already developed entry market for hydrogen in the mobility sector.

Even in the short term, **hydrogen** produced with renewable electricity can be used in refineries to produce petrol and diesel. This will help to reduce emissions from the existing production infrastructure and fleets of vehicles.

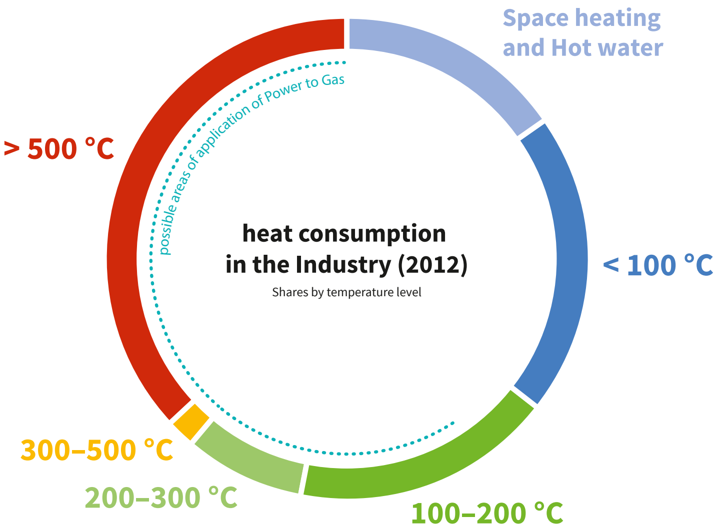
Markets for Power to Gas (4)

Greenhouse gas emissions of various fuels and types of drive



Source: dena (2015): 3rd Interim Report of the Initiative for Natural-Gas-Based Mobility

Markets for Power to Gas (5)



Source: Prognos (2014): Potential and cost-benefit analysis regarding the possible uses of combined heat and power generation (implementation of the EU energy efficiency directive) and evaluation of the combined heat and power generation act in 2014

Industrial sector

Industry has a very high demand for constant high-temperature process heat. Around 85 per cent or 440 TWh is needed for processes of 100 to over 1,000 degrees. **Efficient high-temperature heat pumps can only produce heat of up to a 140 degrees. The use of synthetic gases for heat generation offers opportunities because the gases can be stored and flexibly provide every temperature level required.**

Furthermore, the **chemical and the raw material industry** need oil and gas for industrial use, e.g. for the production of plastics. It is estimated that the demand for Power to Gas to substitute these raw materials will be 293 TWh in 2050.

For **steel production** in a steel mill, renewable hydrogen which is used instead of coal coke to reduce iron ore can reduce CO_2 emissions. Apart from the hydrogen, the electrolytically produced oxygen can also be used directly in the steel mill process. Today, the energy supply of a steel mill already comes from various energy sources. **Power-to-Gas-products could cut process-related GHG emissions in industry by about 75 percent compared to 2010 and shrink them down to 14 million tons of CO_2eq by 2050.**

Economic situation of Power-to-Gas-plants (1)

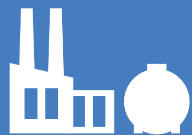
Power purchase options

Electricity market
High burden on electricity purchase prices due to levies and shares in costs

Ancillary services

Non-integratable electricity
Limited possibilities of use

Power-to-Gas-plants
Industrialisation holds potential for cost degression and increased efficiency



Output side
Low revenue opportunities for PtG products

Products for the heating sector

Products for the transport sector

Products for the industrial sector

Products for the Electricity market

Economic situation of Power-to-Gas-plants (2)

Operational costs are burdened by high power purchase prices
The operation of Power-to-Gas-plants currently involves high costs. Disadvantages compared to other energy sources arise primarily from the fact that electricity is currently burdened to a greater extent with various levies and contributions. The Renewable Energy Sources Act surcharge and the grid charges in particular burden the electricity price. As a rule, the purchase of electricity for Power-to-Gas-plants is fully liable to charges and levies.

There are hardly any financial incentives for running Power-to-Gas-plants in a systemically useful way
Power-to-Gas-plants have the great advantage not only of enabling the use of renewable electricity in the heat, transport and industrial sectors, but also of being able to provide a wide range of system services for the electricity system. For example, several PtG plants already offer balancing power. Moreover, PtG systems could in particular be employed to harness RE quantities that cannot otherwise be integrated as switchable loads or through redispatch. These could not be integrated into the grid or the market and were therefore switched off via the feed-in management or the 6-hour rule, cf. Section 24 EEG. At present, however, there are no financial incentives for the utilisation of nonintegratable electricity through a systemically useful running of PtG plants.

There are no overarching incentives for the avoidance of CO_2 and the substitution of fossil energy sources
To date, no direct, consistent and cross-sectoral steering effect exists for the reduction of CO_2 emissions. At present, only individual areas are regulated and/or individual technology options are promoted under different laws.

There are only low revenue opportunities for PtG products
A lack of incentives to reduce CO_2 also means that there are currently only limited opportunities for revenue from PtG products for the customer. Moreover, at present there is no approach that is open to a range of technologies within the energy industry. Many laws discriminate against Powerto-Gas-plants and their products vis-à-vis other established technologies, and unnecessarily restrict their use.

Obstacles to Power to Gas and derived recommendations for action

The current legal framework is not open to a range of technologies and favours established technologies over innovative processes and technologies. In the further development of framework conditions, care must be taken to ensure that the opportunities for **multiple use of Power-to-Gas-plants for different areas of use are made possible (multi-use).** The aim should also be to **establish a level playing field at intersectoral borders in the sense of an Integrated Energy Transition and uniform incentives to reduce CO_2**. Against this backdrop, the partners of the Strategy Platform advocate the following recommendations for action:

Obstacle	Derived recommendation for action
Incentives to use modern fuels in the transport sector are not sufficient Current legislation gives little incentive to use alternative fuels. Although electricity-based fuels count towards the rate of reduction in greenhouse gas emissions there are restrictions on them which relate to the purchase of electricity and the technologies used. Furthermore, in contrast to biofuels, the use of renewable hydrogen in fuel refineries has not yet been recognised as an emission reduction measure.	**Greater promotion of advanced fuels** ■ Introduction of an ambitious sub-quota for advanced fuels (38th BImSchV, Federal Emissions Control Directive) ■ Recognition of liquid synthetic fuels as advanced fuels (BImSchV) ■ Extended options for purchasing electricity in the 37th BImSchV and blending of hydrogen in the natural gas network for inclusion in the rate of GHGs ■ Recognition of the reduction of emissions resulting from the use of renewable hydrogen in refineries in the context of the GHG reduction quota (BImSchG) ■ Use of a well-to-wheel approach in calculating fleet emissions (Regulation (EC) No. 443/2009)

Obstacle	Derived recommendation for action
No incentives for the use of synthetic renewable energy sources in industry The Greenhouse Gas Emissions Trading Act (TEHG) allows industry to use biomass to reduce emissions. The use of renewable hydrogen or methane is not yet recognised as a mitigation measure within the scope of emissions trading.	**Recognise renewable gases within the scope of the TEHG** Industry should be able to include electricity-based energy sources in the emissions report within the scope of emissions trading (§ 5 TEHG).
No incentives to use synthetic renewable gases in the heating sector In the Renewable Energies Heat Act (EEWärmeG), synthetic, electricity-based gases are not included in the definitions of renewable energies (§ 2) and can therefore not be included in the usage obligation (§ 3).	**Consideration of renewable gases in the heating sector in EEWärmeG/GEG and KWKG** ▪ Synthetic renewable gases should be recognised as renewable energies in the amendment of the Renewable Energies Heat Act. ▪ This makes a recalculation of the primary energy factors necessary. ▪ Under the Combined Heat and Power Act (KWKG), operators should be able to claim the CHP bonus for the use of synthetic gases
Restrictions for electricity grid operators in the procurement of supplementary power Pursuant to § 13(6a) EnWG, grid system operators may bind Power-to-Heat-plants contractually as a switchable load useful for the system if the plant operator in return reduces the output of his CHP plant. Further technologies could by ordinance also be used as switch-able loads where the planned installed capacity of 2 GW for Power to Heat is not achieved in the grid expansion area.	**Switchable load ordinance open to various technologies** The existing authorisation under the ordinance should be used, in the event that the planned 2 GW capacity is not achieved with Power-to-Heat plants within a defined period of time, in order to make the arrangements for further switchable loads open to various technologies and also to enable the use of sector coupling technologies such as Power to Gas (§ 13i (1) and (2) EnWG).

Obstacle	Derived recommendation for action
Lack of incentives to use flexibility options in a way that benefits the grid The current wording of the German Incentive Regulation Ordinance (ARegV) and the Electricity Grid Charges Ordinance ((StromNEV) favour investment-cost-intensive solutions, e.g. grid expansion measures as opposed to operating-cost-intensive solutions such as Power-to-Gas-plants. As a result, the network operator receives lower revenues when using, i. a., Power-to-Gas-plants for bottleneck management.	**Create revenue opportunities for use of Power-to-Gas-plants which is beneficial to the grid** Grid operators should be given the chance to compensate the more extensive, grid-friendly use of flexibilities, including Power-to-Gas-plants, above and beyond the provision of balancing energy. They should be able to use them e.g. for redispatch or feed-in management (e.g. by means of amendments to the EnWG, EEG, ARegV, Strom-NEV and, where applicable, BNetzA provisions).
Lack of incentives to use unsubsidised quantities of electricity Renewable energy systems that will no longer be subsidised under the EEG after 2020 have little incentive to continue operating these systems due to their low revenue potential. Repowering will not be possible for all sites.	**Enable use of non-subsidised RE electricity outside of the EEG** ■ Reduction in the Renewable Energy Sources Act (EEG) surcharge, e.g. for electricity from Renewable Energy plants which are not (or no longer) eligible for subsidies under the EEG
Lack of incentives to use non-integratable electricity quantities § 27a of the EEG 2017 does not allow operators of renewable energy plants who receive subsidies under the EEG to use the electricity temporarily for their own supply and thus operate a Power-to-Gas-plant, for example. If non-integratable electricity is sold to third parties (e.g. a Power-to-Gas-plant) then the full EEG surcharge must be paid for it.	**Enable use of non-integratable RE quantities** ■ Allow possibility of own use of RE electricity in accordance with § 27a EEG for periods of feed-in management ■ Implement reduction in electricity tax and EEG surcharge for electricity that cannot be integrated into the grid (cut-off electricity) ■ Openly encourage the use of electricity that cannot be integrated into the grid in a way that is open to a range of technologies. This can be achieved, for example, by reducing levies and contributions. The suitability of various instruments should be assessed.

Obstacle	Derived recommendation for action
Electricity and gas infrastructures are planned and developed seperatly At present, the planning processes envisage an isolated approach for electricity and gas grids. In the interests of an Integrated Energy Transition, plans for infrastructures (electricity-, gas-, heating-grids and transport infrastructures) must be coordinated in good time.	**Integration and joint planning of infrastructures** ■ The extent to which an integrated planning of electricity and gas infrastructures can improve the efficiency and reliability of supply should be examined. ■ In a first step, for example, a coordination process can be introduced between transmission system operators, distribution grid operators and long-distance gas grid operators which takes account of shared scenarios (EnWG, § 12a et seq. and § 15a et seq).
Inadequate infrastructure for advanced fuels in the transport sector In the transport sector, a lack of infrastructure is a major obstacle to a widespread use of alternative fuels and propulsion technologies and to the transportation and distribution of powerfuels. The national strategic framework governing the development of infrastructure for alternative fuels sets only minimal targets for a basic network of CNG, LNG and H_2 filling stations in Germany by 2030.	**Develop infrastructures for alternative fuels** ■ At the same time as the development of the infrastructure for electromobility, in particular with regard to road freight transport a nationwide range of natural gas and hydrogen filling stations should be rolled out. ■ To this end, it is essential to build hydrogen and natural gas filling stations above and beyond existing targets and irrespective of the number of vehicles.
Restrictions on the feed-in of hydrogen into the natural-gas grid ■ The feed-in of hydrogen into the natural-gas grid is restricted. Technical thresholds exist in this respect (DVGW [German Technical and Scientific Association for Gas and Water] regulation G262) as well as restrictions imposed by federal authorities (BNetzA, PtB). The approval procedure is a risk for plant operators as it involves individual case decisions about the approval of feed-in plants. ■ In the European gas network, the „export“ of hydrogen-enriched natural gas is hampered or prevented by national threshold values in neighbouring countries.	**Clarify unresolved questions on the feed-in and transmission of hydrogen in the natural-gas grid** ■ Binding and universal regulations for feed-in systems must be developed and enforced. ■ Throughout Europe, it should be examined what amount of hydrogen admixture is suitable without affecting the products of gas purchasers (e.g. copper producers). Subsequently, Europe-wide, binding standards should be introduced.

Glossary

Abbreviations	Descriptions
ARegV	German Incentive Regulation Ordinance
BNetzA	Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railway
CNG	Compressed Natural Gas
CO_2	Carbon dioxide
EE	Renewable energy
EEG	Act for the expansion of renewable energy
EEWärmeG	Renewable Energies Heat Act
EU	European Union
EU ETS	Emissions trading system of the EU
GEG	Buildings Energy Act
H_2	Hydrogen
kWh/MWh/ GWh/TWh	Kilowatt hours/Megawatt hours/ Gigawatt hours / Terrawatt hours

Abbreviations	Descriptions
KWKG	Combined Heat and Power Act
LNG	Liquefied Natural Gas
ÖPNV	Public transport
PTB	Physical Technical Federal Institute
PtG	Power to Gas
PtL	Power to Liquid
PtX	Collective term for all technologies that make electric power usable elsewhere
SNG	Synthetic Natural Gas
StromNEV	Electricity Grid Access Charges Ordinance
TEHG	Greenhouse gas emissions trading law
THG	Greenhouse gases

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